AAMRL-TR-87-046

FIT EVALUATION OF FEMALE BODY ARMOR (U)

GREGORY F. ZEHNER
ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

CAY ERVIN
ANTHROPOLOGY RESEARCH PROJECT, INC.

KATHLEEN M. ROBINETTE
ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

PATRICIA DAZIENS
ANTHROPOLOGY RESEARCH PROJECT, INC.

JUNE 1987

FINAL REPORT FOR PERIOD JULY 1986 - FEBRUARY 1987

Approved for public release; distribution is unlimited.

ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from Armstrong Aerospace Medical Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies and their contractors registered with Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
Cameron Station
Alexandria, Virginia 22314

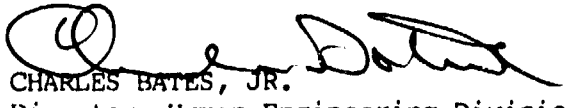
TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-87-046

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AAMRL-TR-87-046
6a. NAME OF PERFORMING ORGANIZATION Anthropology Research Project, Inc. 6b. OFFICE SYMBOL (*If applicable*)	7a. NAME OF MONITORING ORGANIZATION Harry G. Armstrong Aerospace Medical Research Laboratory
6c. ADDRESS (*City, State, and ZIP Code*) 503 Xenia Avenue Yellow Springs, Ohio 45387	7b. ADDRESS (*City, State, and ZIP Code*) Wright-Patterson Air Force Base, Ohio 45433-6573
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (*If applicable*)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-85-C-0531
8c. ADDRESS (*City, State, and ZIP Code*)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62202 F	7184	08	42

11. TITLE (*Include Security Classification*)

Fit Evaluation of Female Body Armor (U)

12. PERSONAL AUTHOR(S)

Zehner, Gregory F.*; Ervin, Cay; Robinette, Kathleen M.*; and Daziens, Patricia

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (*Year, Month, Day*)	15. PAGE COUNT
Final	FROM JUL 1986 TO FEB 1987	1987 June	60

16. SUPPLEMENTARY NOTATION

*Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio

17. COSATI CODES			18. SUBJECT TERMS (*Continue on reverse if necessary and identify by block number*)
FIELD	GROUP	SUB-GROUP	
05	05		Female body armor; Fit/protection; Vests; Fit testing
06	17		

19. ABSTRACT (*Continue on reverse if necessary and identify by block number*)

The object of this research was to evaluate the current issue MS-1 (Natick) female body armor vest, and to examine design modifications which would enhance the protection level by improving the fit. Subjects in the study were 37 female Air Force police trainees selected to represent a range of body sizes found in the overall USAF population. The MS-1 and two commercially available vests were evaluated for fit, comfort, and coverage in a series of measurements and observations. On the whole, the MS-1 vest compared favorably with the commercial garments. Some design changes are suggested to improve fit and coverage. Keywords: bullet proof vests, anthropometry, protective clothing

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (*Include Area Code*)	22c. OFFICE SYMBOL
Kathleen M. Robinette	513-255-8810	AAMRL-HEG

DD Form 1473, JUN 86 *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

SUMMARY

Although female body armor has been adapted to accommodate the upper body build of women, the stiff materials and the variability of women's shapes and sizes often make it difficult to obtain a good fit and adequate protection. The purpose of this evaluation was to determine how well the current issue MS-1 (Natick) female body armor fits, and how it compares with other commercially available vests. Thirty-seven Air Force police trainees, representing a range of body sizes found among women in the general USAF population, tried on the MS-1 and two commercial vests. Subjects were measured, both in and out of the vests, and a series of observations was made while subjects stood, sat, and moved around in various ways (e.g. bending and twisting). The vests were rated in terms of fit, comfort, and coverage. Results indicated that the MS-1 vest compared favorably with the commercially available armor, although all three had clearly evident inadequacies. Suggestions for improving fit include: providing larger sections of velcro so that strap fasteners can be secured more tightly on smaller women; making straps of less elastic material which currently causes the vests to sag; and providing sizes which incorporate shorter torso lengths. Designers are, however, urged to exercise caution in making such changes without additional fit testing since the solution of one problem can create another.

PREFACE

This study was conducted by the Anthropology Research Project, Inc. under Air Force Contract F33615-85-C-0531 (Task 718408) with the Harry G. Armstong Aerospace Medical Reseach Laboratory, Wright-Patterson Air Force Base, Ohio. Kathleen M. Robinette was the contract monitor.

The authors would like to thank members of 5280th TCHTG, especially Col. Doran, Major Barlow, and SMSGT Eull, Lackland Air Force Base, San Antonio, Texas, for providing test subjects and for making arrangements for the fit testing; and to the 2750th SP/SPO, Wright-Patterson Air Force Base for providing subjects and much needed feedback for the preliminary testing.

We would also like to acknowledge Mrs. Belva Hodge for preparation of the manuscript and Mrs. Ilse O. Tebbetts for editing.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

FIT EVALUATION OF FEMALE BODY ARMOR

INTRODUCTION

An increasing number of women are joining the ranks of the Air Force security police but, because of their shape, there is some concern that females are less well protected than are men by the currently-issued military body armor, the MS-1 (Natick) vest. On some individuals, this vest leaves a large oval-shaped area exposed around the shoulder and chest, and a gap between the breastbone and the vest. The purpose of this research effort was to evaluate the fit of the MS-1 vest and several other commercial vests, and to suggest possible design and/or sizing modifications for currently available female body armor.

As part of this research effort a brief literature review was conducted to obtain information on how body armor should fit and how fit affects protection. Nothing illuminating was found in the literature on this subject. Inquiries to vest manufacturers and security police officials did not produce any definitive answers, but practical experience with body armor indicates that on balance, a snug fit is desirable, according to security police sources.

In a related effort we attempted to determine how well civilian female police officers rated the fit of their body armor. Questionnaires (Figure 1) were sent to the Illinois Women in Law Enforcement organization for inclusion in their monthly newsletter. The small return (19 of 500) prevented any useful analysis but, in general, the returned questionnaires gave mixed comments. For example, roughly half of the women rated the vests too long, while the other half thought they were too short. Only six of the women reported having a "good" fit; the remaining rated the vest fit as either "fair" or "poor". Thus, while the respondents did not agree on the nature of the problem, the majority of them were dissatisfied.

METHODS

The Vests

Four commercially available vests were acquired for use in the evaluation. As a result of pilot testing, only two of the four were used in the field evaluation. One was eliminated because of its similarity to another slightly larger one; a second vest was not included because its fit and coverage were too poor even to be considered. The MS-1 vest and the two vests selected for comparison in the fit evaluation are described below.

QUESTIONNAIRE

The Anthropology Research Project is currently working on an Air Force contract to assess the fit of female body armor. As preliminary work we are circulating a questionnaire to determine possible problem areas in fitting women. To help us determine which women have the most difficulty obtaining a "good" fit, we have included some questions on sizing. The questionnaire is completely anonymous; do not put your name on it. If you need more space, write on the back.

1. How many hours a day would you estimate you wear body armor? (circle one)
   1-2 3-4 5-6 7-8

2. What type of body armor (manufacture and style) do you currently wear?
   _____

3. What size body armor do you wear? _____ What is your chest (bra) size? _____

4. What is your height? _____ Weight? _____

5. Was your armor custom made or an off-the-shelf size? (circle one)

6. How would you assess the fit of the armor? (circle one)
   GOOD FAIR POOR

7. If the armor does not fit well please indicate the trouble area(s) by circling one or more of the following.

too small	chest	too big
too small	waist	too big
too small	neck	too big
too short	torso	too long
too small	armholes	too big

8. How would you rate the comfort of the armor? (circle one) GOOD FAIR POOR
   Are there some positions (for instance, sitting) which are uncomfortable when wearing the armor? _____ If so, please specify. _____
   _____

9. How would you improve the fit of the armor? _____
   _____

10. Have you ever NOT worn body armor because of problems with fit or comfort? (circle one) YES NO

11. Is your body armor difficult to put on or take off? _____ If so, please specify. _____
    _____

12. Have you worn other body armor that is superior in fit or comfort to your current body armor? _____ If so, please specify. _____
    _____

13. We would appreciate any helpful comments you may have. _____
    _____
    _____

Figure 1. Female Body Armor Questionnaire.

The current issue Department of Defense (DOD) armor (Natick MS-1 vest, Figure 2) was designed by the Army's Natick Research, Development and Engineering Center at Natick, Massachusetts. The vest, manufactured by Protective Apparel Corporation, was available for testing in three sizes: Small Regular, Medium Regular, and Large Regular. (It should be noted that the original sizing system included eight sizes: two lengths were available in Extra Small, Small, Medium, and Large but only three sizes are issued by the Air Force.) The vest consists of front and back fabric sections with Kevlar insert panels. The fabric portion extends a few inches below the belt line, creating a shirttail-like effect. The panels can be made to join or overlap at the sides by means of two elastic straps attached to the back panel and fastened to 1 1/4" x 4" velcro strips on the front panel. Elastic shoulder straps are attached to the back panel and fastened to 1 1/4" x 3" velcro strips on the front panel. This allows for some adjustability. Seams on both sides of the front panel create darts.

Figure 2. Natick MS-1 vest.

The two commercially designed vests used in the study were manufactured by Safariland Ballistics. The vest referred to as the "blue" vest (Figure 3) in the fit evaluation was available in sizes Small, Medium, Large, and Extra-large. Again, Kevlar inserts fit in the front and back fabric shell. The back panel wraps around the sides and is secured to the velcro on the smaller, rounded front section by elastic straps. For the side straps a single 3 3/4" x 6" velcro receiver is located in the center of the front panel. At the shoulders the receiving areas measure 1 1/4" x 2 1/2". A pocket is provided for the removable metal contour plate insert. Two dart-like seams begin along the bottom edge and end at the breast point. The blue vest does not have the shirttail extension found on the MS-1 vest, but ends at the bottom of the Kevlar panel.

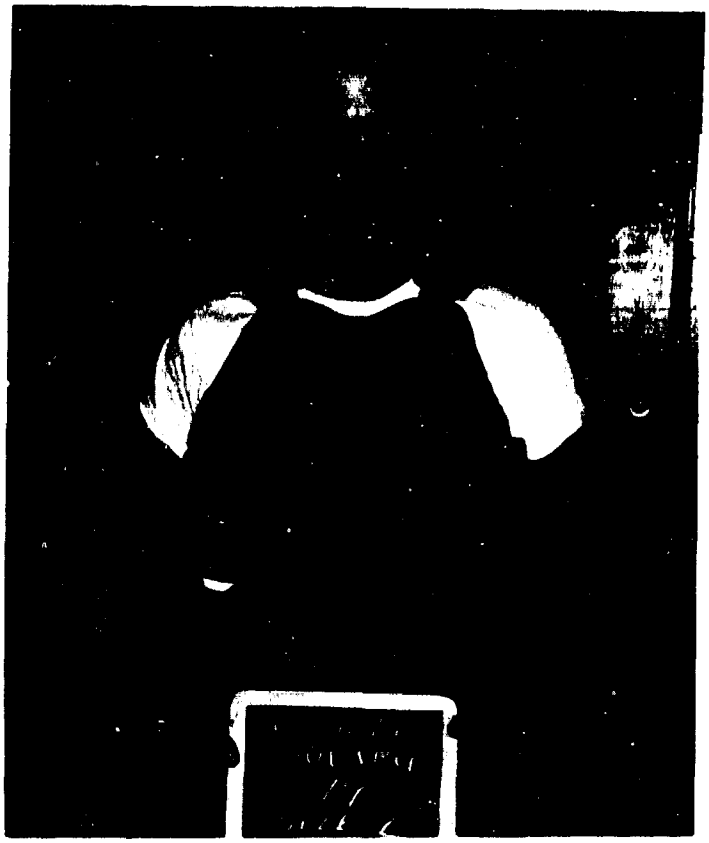


Figure 3. Safariland ("blue") vest.

The third vest, labeled "t-shirt" (Figure 4) in the evaluation, was available in three sizes: Small, Medium, and Large. The vest consists of a front and back Kevlar panel in a fabric shell. The back wraps around the sides to overlap the front section. In lieu of the velcro fasteners, a t-shirt-like garment made of an elasticized mesh fabric is attached to the shell at the shoulders and keeps the Kevlar panels in place.

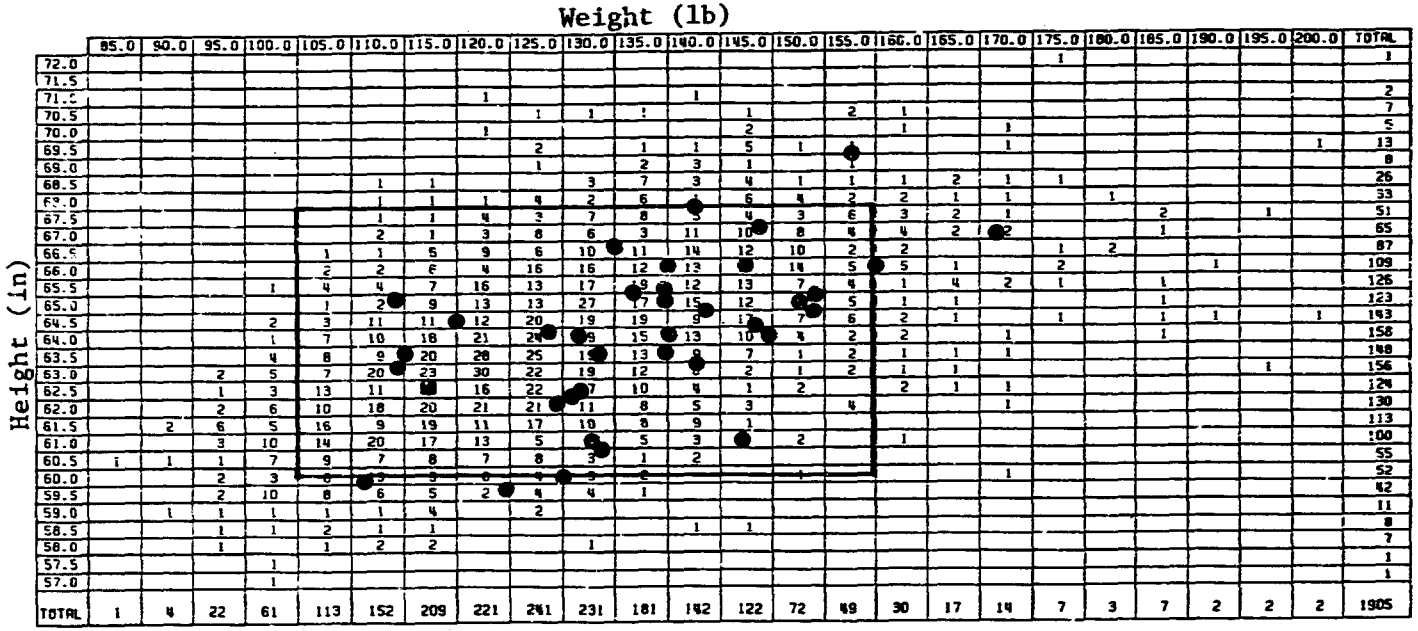
Figure 4. Safariland ("t-shirt") vest.

The neckline and armholes are rounded. A zipper in the front of the garment facilitates donning and doffing. The dart-like seams in front are similar in design to the MS-1 vest. Like the other commercially designed armor, the t-shirt vest terminates at waist level.

Subjects

To obtain a sufficient sample of the user population, the fit evaluation was conducted at Lackland Air Force Base, San Antonio, Texas, which is the training center for the Air Force security police. Thirty-seven female trainees participated. The subjects were from one of two areas of Air Force security police: law enforcement or security.

Figure 5 shows a height-weight bivariate distribution table of the 1968 USAF women. The outlined interior rectangle encompasses the 5th through 95th percentile USAF women in both height and weight. Each of the 37 subjects in the fit test sample is designated by a black dot on the plot. It can be seen that the test sample is a good representation of the general body size distribution of Air Force women.



Height (in)	85.0	90.0	95.0	100.0	105.0	110.0	115.0	120.0	125.0	130.0	135.0	140.0	145.0	150.0	155.0	160.0	165.0	170.0	175.0	180.0	185.0	190.0	195.0	200.0	TOTAL
72.0																			1						1
71.5																									
71.0								1				1													2
70.5									1	1	1		1		2	1									7
70.0								1					2			1		1							5
69.5									2		1	1	5	1	1			1						1	13
69.0									1		2	3	1		1										8
68.5						1	1			3	7	3	4	1	1	1	2	1	1						26
68.0						1	1	1	4	2	6	4	6	4	2	2	1	1		1					33
67.5						1	1	4	3	7	8	5	4	3	6	3	2	1			2		1		51
67.0						2	1	3	6	6	3	11	10	8	4	4	2	2			1				65
66.5					1	1	5	9	6	10	11	14	12	10	2	2			1	2					87
66.0					2	2	6	4	16	16	12	13	13	14	5	5	1		2			1			109
65.5				1	4	4	7	16	13	17	9	12	13	7	4	1	4	2	1		1				126
65.0					1	2	9	13	13	27	17	15	12	8	5	1	1				1				123
64.5				2	3	11	11	12	20	19	19	9	11	7	6	2	1		1		1	1		1	143
64.0				1	7	10	18	21	24	29	15	13	10	4	2	2		1			1				158
63.5				4	8	9	20	28	25	19	13	8	7	1	2	1	1	1							148
63.0			2	5	7	20	23	30	22	19	12	9	2	1	2	1	1						1		156
62.5			1	3	13	11	18	16	22	27	10	4	1	2		2	1	1							124
62.0			2	6	10	18	20	21	21	11	8	5	3		4			1							130
61.5		2	6	5	16	9	19	11	17	10	8	9	1												113
61.0			3	10	14	20	17	13	5	6	5	3	6	2		1									100
60.5	1	1	1	7	9	7	8	7	8	3	1	2													55
60.0			2	3	6	6	5	6	4	5	2							1							52
59.5			2	10	8	6	5	2	4	4	1														42
59.0		1	1	1	1	1	4		2																11
58.5			1	1	2	1	1					1	1												8
58.0			1		1	2	2			1															7
57.5				1																					1
57.0				1																					1
TOTAL	1	4	22	61	113	152	209	221	241	231	181	142	122	72	49	30	17	14	7	3	7	2	2	2	1905

Figure 5. A bivariate frequency table for height and weight for 1968 Air Force Women with body armor sample superimposed.

Figure 6 shows the distribution of bust circumference and anterior waist length (from the base of the neck to the waist) for the same USAF women's population. On this diagram the women in the test sample are designated by L, M, or S, in each case indicating the MS-1 vest size assigned to her.

Selected, lightly-clad measurements were made on the test subjects. Table 1 shows the range of 1968 USAF women's measurements represented by the range of measurements obtained from the test subjects for each dimension. Again, the sample subjects represent the larger survey surprisingly well.

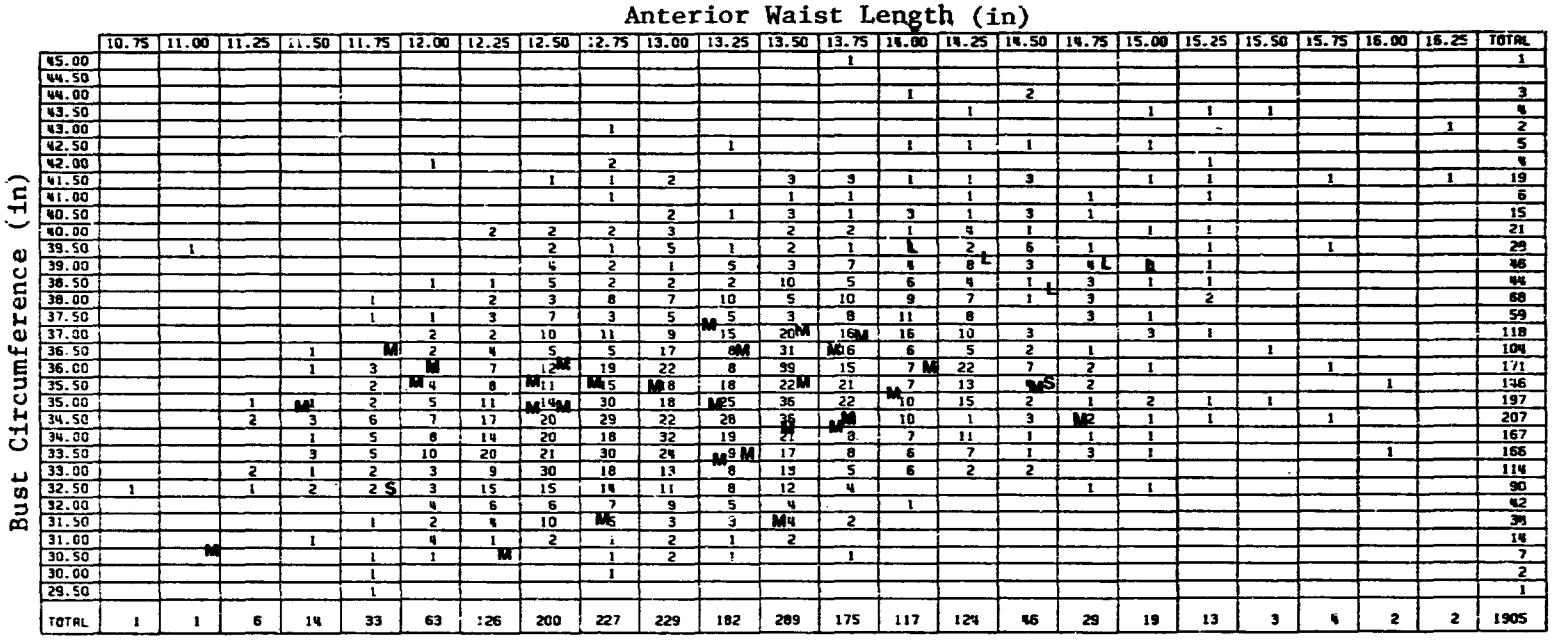
Procedures

In general, the fit test was conducted as a laboratory exercise. Subjects were assigned a vest of the appropriate size and then asked to move around in selected ways (e.g. sit, stand, bend, twist, and assume a pistol-firing position). Two investigators observed the movements and ranked a number of fit-related factors on a scale of one (good) to three (poor). The procedure was repeated for each subject wearing all three vests. For the evaluation each subject wore her typical fatigue uniform with a web belt, poncho, canteen, ammunition pouch, and flashlight.

Before arriving at this study design, patrol dog handlers were interviewed, and field exercises of security police were observed to determine if they presented any unusual fit problems not covered by the laboratory assessment. While these subjects carried additional gear, they did not present any additional fit problems.

For the study, each subject was given a brief explanation, and then assigned a vest by the investigators. The procedure was the same regardless of body size. First, the subject tried on the size Medium or, in the case of the blue vest, size Large because this vest came in a four-size system and the size Large was most nearly comparable to the size Medium in the other vests. If the initial vest was too small or too large, the adjacent size in the indicated direction was tried. Body coverage was considered to be a more important consideration than comfort although both were considered. For example, in several cases the size Large was too long and interfered to some extent with the subject's movements, but covered the body in the area of the armhole well. On these subjects, the Medium vest provided a more comfortable length, but left large areas of the chest exposed (Figure 7). We selected the larger size in these cases since the large openings at the armholes left the heart exposed to a round fired from an angle about 45 degrees from directly in front of the officer. Obviously, this principle could be carried to an extreme by putting the largest vests on small subjects to increase coverage. The trade-offs were carefully weighed and in nearly all cases the proper size was quite obvious.

Early in the testing the MS-1 was regarded as a three-size vest. As the analysis proceeded, however, it was discovered that size Small and size Medium differed only in the length of the elastic straps at the shoulders. The small size actually had longer straps (Figure 8). The size Small was dropped from further consideration since longer straps at the shoulders were never necessary. It is unclear if this sizing anomaly was the result of mislabelling or was intentional, but it should be investigated further.



	10.75	11.00	11.25	11.50	11.75	12.00	12.25	12.50	12.75	13.00	13.25	13.50	13.75	14.00	14.25	14.50	14.75	15.00	15.25	15.50	15.75	16.00	16.25	TOTAL
45.00													1											1
44.50																								
44.00														1		2								3
43.50															1			1	1	1				4
43.00									1										-				1	2
42.50											1			1	1	1		1						5
42.00						1			2										1					4
41.50								1	1	2		3	3	1	1	3		1	1		1		1	19
41.00									1			1	1		1		1		1					5
40.50										2	1	3	1	3	1	3	1							15
40.00							2	2	2	3		2	2	1	4	1		1	1					21
39.50		1						2	1	5	1	2	1	L	2 L	6	1		1		1			29
39.00								4	2	1	5	3	7	4	8 L	3	4 L	h	1					46
38.50						1	1	5	2	2	2	10	5	6	4	1 L	3	1	1					44
38.00					1		2	3	8	7	10	5	10	9	7	1	3		2					68
37.50					1	1	3	7	3	5	5 M	3	8	11	8		3	1						59
37.00						2	2	10	11	9	15	20M	16M	16	10	3		3	1					118
36.50				1	M	2	4	5	5	17	8M	31	M16	6	5	2	1			1				104
36.00				1	3	M	7	12M	19	22	8	39	15	7 M	22	7	2	1			1			171
35.50					2	M 4	8	M11	M15	M 8	18	22M	21	7	13	M S	2					1		146
35.00			1	M	2	5	11	M14M	30	18	M25	36	22	M 10	15	2	1	2	1	1				197
34.50			2	3	6	7	17	20	29	22	28	36	M	10	1	3	M2	1	1		1			207
34.00				1	5	8	14	20	18	32	19	21	8	7	11	1	1	1						167
33.50				3	5	10	20	21	30	24	M9 M	17	8	6	7	1	3	1				1		168
33.00			2	1	2	3	9	30	18	13	8	13	5	6	2	2								114
32.50	1		1	2	2 S	3	15	15	14	11	8	12	4				1	1						90
32.00						4	6	6	7	9	5	4		1										42
31.50					1	2	4	10	M6	3	3	M4	2											38
31.00				1		4	1	2	1	2	1	2												14
30.50		M			1	1	M		1	2	1		1											7
30.00					1				1															2
29.50					1																			1
TOTAL	1	1	6	14	33	63	126	200	227	229	182	209	175	117	124	46	29	19	13	3	4	2	2	1905

Figure 6. A bivariate frequency table for anterior waist length and bust circumference for 1968 Air Force Women with MS-1 vest size assigned to each subject superimposed.

TABLE 1

LIGHTLY-CLAD MEASUREMENTS
(age in yrs, weight in lbs,
all others in inches)

	1986 TRAINEES (n=37)		1968 AIR FORCE WOMEN (n=1905)
	Mean	Range	Approximate Percentile Range
Age	20.4	18.0 - 27.0	1st - 83rd
Weight	135.0	109.0 - 169.0	13th - 98th
Height	64.1	59.6 - 69.3	3rd - 99th
Suprasternale	52.3	48.2 - 57.9	3rd - 99th
Waist Height	39.8	35.7 - 47.5	1st - 99th
Cervicale Height	55.0	51.2 - 60.6	4th - 99th
Chest Circumference	35.4	30.6 - 39.4	1st - 95th
Interscye Front	13.7	11.9 - 15.6	not measured
Waist Front	13.2	11.1 - 15.0	1st - 99th
Interscye Back	13.6	11.1 - 16.3	1st - 99th
Waist Back	15.6	13.5 - 18.7	1st - 99th
Chest Depth (Midsagittal)	7.1	5.9 - 8.5	not measured
Chest Depth, (Bustpoint)	9.1	7.7 - 10.3	1st - 90th
Suprasternale Height, Sitting	21.8	19.3 - 23.5	not measured
Cervicale Height, Sitting	24.6	21.8 - 26.8	not measured

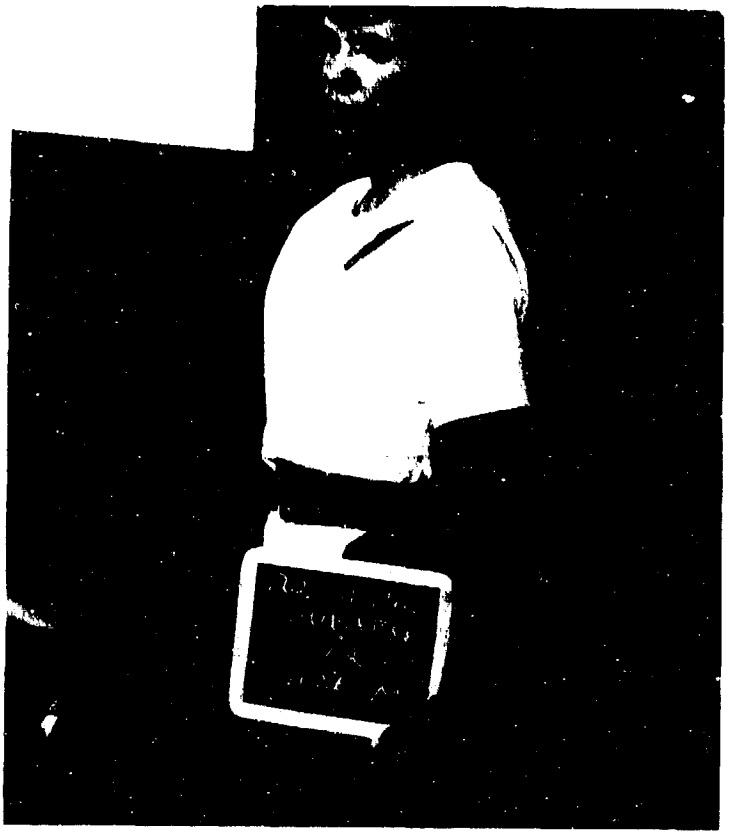


Figure 7. Exposed area of the chest at the armhole.

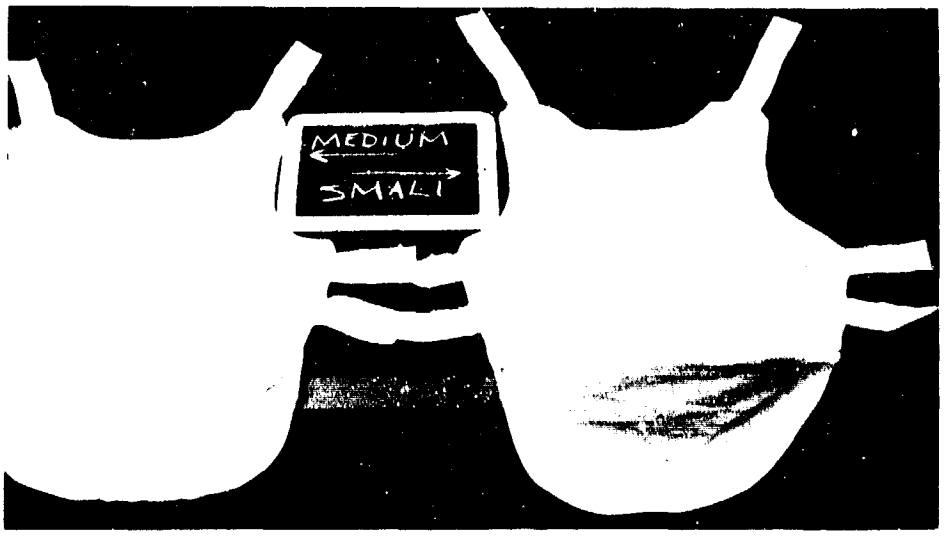


Figure 8. Similarity of the small and medium MS-1.

Figure 9 is the data sheet used in the field. Fourteen lightly-clad and 12 vested measurements (in each of the three types of vest) as well as 36 qualitative assessments of fit, coverage and comfort were made on each of the 37 subjects. The measurements are described in the Appendix. The lightly-clad dimensions were used to compare the sample to the large scale Air Force survey information (as in Figures 5 and 6 and Table 1). Some of these measurements can be used to derive the relationship of vest location relative to anatomical landmarks. For example, subtracting Kevlar top height in front from suprasternale height gives the distance from the top of the vest to the bottom of the neck. The main reason for taking these measurements, however, was to try to determine the relationships between the dimensions and fit, and to identify, if possible, what body type was getting a good (or poor) fit.

The qualitative assessment of fit, coverage and comfort of the vests was based upon the judgment of two investigators who used a ranking of good, fair or poor. In general, the ranking for fit was based upon the assumption that a snug fit, with the armor lying directly on the skin was most desirable. The rankings for coverage at the sides of the vests were specifically 1, 2, or 3 when front and back panels overlapped, met, or left an area exposed, respectively. In other areas of coverage, rankings were based on judgment.

Both fit and coverage were graded in the standing and seated positions since security police spend a great deal of time in both postures. The interface between the vest and the utility belt with associated gear was of particular concern and was reflected in several assessments: interference with utility belt (Figure 10), side-bending interference (Figure 11), and bottom-front interference (not shown). The seated position results in several problems not encountered while in the standing position. These can include chafing or rubbing, interference with neck flexion as a result of the vest riding up, or shifting of the vest in other directions. These problems were added to the list of factors to be assessed.

WOMEN'S BODY ARMOR EVALUATION

Name _____ Date _____

Subject Number _____ Measurer _____

_____

LIGHTLY-CLAD MEASUREMENTS

Age	_____	Intereye Front	_____
Bra Size	_____	Waist Front	_____
Weight	_____	Intereye Back	_____
Height	_____	Waist Back	_____
Supra. Height	_____	Chest Depth, Mid-Sag.	_____
Waist Height	_____	Chest Depth, Bustpoint	_____
Cervicale Height	_____	Supra. Height, Sitting	_____
Chest Circumference	_____	Cervicale Ht. Sitting	_____

VESTED MEASUREMENTS

	Natick	Blue	T-Shirt
VEST SIZE	_____	_____	_____

Standing

Kevlar Top Ht, Front			
Kevlar Bottom Ht, Front			
Kevlar Top Ht, Back			
Chest Depth, Mid Sag.			
Chest Depth, Bustpoint			
Shoulder Gap Depth, Front			
Gap Breadth, Front			
Gap Height, Under Arm			
Gap Breadth, Back			
Gap at Side			

Sitting

Kevlar Top Ht, Front			
Kevlar Top Ht, Back			

Figure 9. The data sheet.

FIT AND COVERAGE ASSESSMENT
1 = Good 2 = Fair 3 = Poor

STANDING

	Natick	Blue	T-Shirt
(Fit)			
Upper Chest			
Bust			
Waist			
(Coverage)			
Top			
Front (Arm Holes)			
Bottom			
Sides			
Back (Top)			
Back (Arm Holes)			

SEATED

	Natick	Blue	T-Shirt
Interfere with Utility Belt			
(Fit)			
Upper Chest			
Bust			
Waist			
Chafing			
Neck Flexion			
(Coverage)			
Top			
Front (Arm Holes)			
Bottom			
Sides			
Shifting			

MOVEMENT:
Bend: Front, Side; Twist; Walk

		Natick	Blue	T-Shirt
Coverage	Back			
	Bottom Front			
	Top			
	Arm Holes			
Interference	Sides			
	Shift During Movement			
	Shift After Movement			
	Interference in Shooting Position			
Chafing				

GENERAL

	Natick	Blue	T-Shirt
Fasteners			
Don			
Doff			
Weight or Bulk			
Trouble Breathing			
Fit/ Coverage (Overall)			
Comfort (Overall)			

Comments _____

_____

_____

_____

_____

_____

_____

Figure 9. (cont'd)

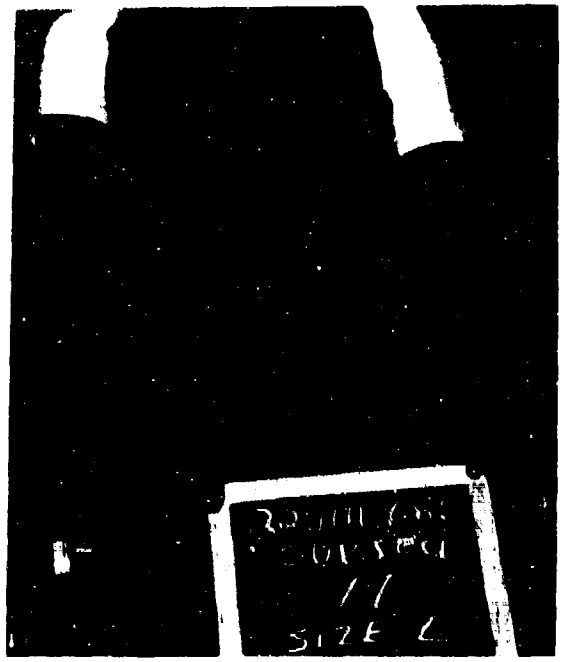


Figure 10. Vest interface with the utility belt.

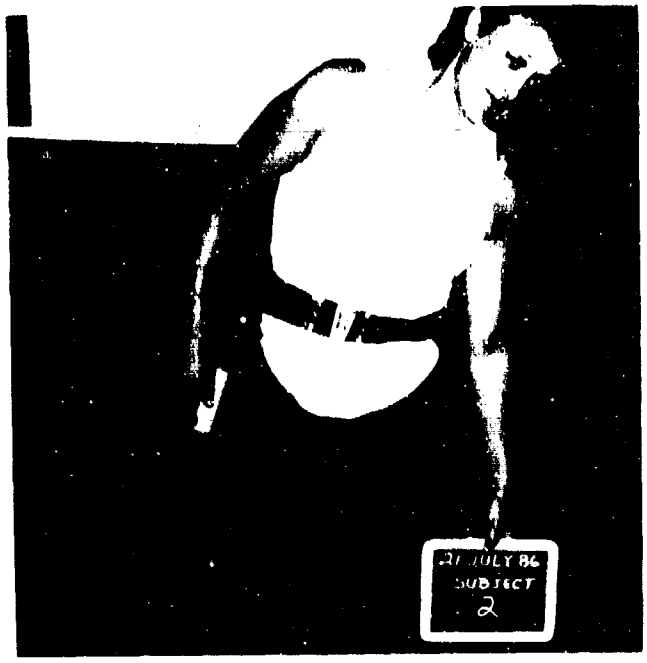


Figure 11. Side to side movement interference.

To assess movement, subjects were required to bend forward and to the sides, twist at the waist, and generally move around. Potential problems under observation included bagging out of the vest and exposing the subject during movement, shifting of the vest out of position after movement, or discomfort or difficulty while assuming a two-hand pistol-firing position (Figure 12).

Figure 12. Vest binding at shoulders and bagging out at base of neck in two-handed firing position.

Finally a general group of problems was evaluated. These included: fastener evaluation, ease of putting on and removing the vests, bulkiness and breathing hindrances, and overall assessment of the fit and coverage as ranked by both investigators with the subject's input. Comments were recorded each time a variable was given a "poor" rating.

RESULTS

Table 2 compares the means and standard deviations for 11 of the 12 vested dimensions. (The gap-at-side measurement presented so little problem that it was dropped from the analysis.) Some simple calculations involving these measurements and the body measurements documented in Table 1 reveal the gaps in the coverage. For example, given a mean suprasternale height of 52.3 inches (from Table 1), and subtracting out the Kevlar Height Front (from

TABLE 2

VESTED MEASUREMENTS
(measurements in inches)

	MS-1		Blue		T-Shirt	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Kevlar Top Height, Front (from floor)	51.7	2.22	51.1	2.11	51.0	2.05
Kevlar Bottom Height, Front (from floor)	41.3	2.22	40.5	2.13	41.5	1.75
Kevlar Top Height, Back (from floor)	52.3	2.24	52.2	2.12	51.4	2.20
Chest Depth Midsagittal	9.8	.61	10.0	.69	9.8	.61
Chest Depth, Bustpoint	9.9	.60	10.2	.69	9.9	.60
Gap* Depth, in Front of Arm	1.2	.54	1.8	.47	1.2	.79
Gap Breadth, in Front of Arm	.7	.30	.9	.37	1.1	.36
Gap Height, Under Arm	2.7	.75	2.7	.74	3.2	.55
Gap Breadth, in Back of Arm	1.4	.42	1.3	.45	1.5	.40
Kevlar Top Height, Front, Sitting	21.1	1.04	20.4	.92	20.2	.94
Kevlar Top Height, Back, Sitting	22.4	.98	22.2	.89	21.7	1.36

* n = 27

the first row in Table 2), indicates that the MS-1 vest (on the average) lies .6 inches below suprasternale, the blue vest 1.2 inches, and the T-shirt 1.3 inches below it. On the lower side of the vest, given a mean waist height of 39.8 inches (again from Table 1), and subtracting Kevlar Bottom Height in Front, the MS-1 vest lies 1.5 inches above this point, the blue .7 inches and the T-shirt 1.7 inches above it. These values involve trade-offs between coverage and comfort and will be discussed further in the next section.

The vested shoulder gap dimensions are particularly important as they represent an area close to the heart where the officer is exposed (see Figure 7). In an attempt to determine if poor fit in this area could be related to specific body sizes or proportions -- e.g. is large chest circumference related to a large gap at the front of the arm? -- we applied correlation and multiple regression techniques and attempted to predict the four gap dimensions in the vested data from the lightly-clad measurements. The correlation matrix was calculated but, in general, the correlations were too low to yield useful information.

Table 3 displays the qualitative ratings given the vests on a number of variables. Once again a good fit was taken to be snug but comfortable. Loose or bagging fit was considered poor because it exposed additional areas of the body, and because the ballistic effect of a round hitting a vest which is not snug against the body is considered to be more serious. Listed on the table are the number of subjects (frequency) receiving each rank (good, fair, poor) and the average value for all subjects in each vest.

Table 4 summarizes Table 3 by combining similar areas of the evaluation into single categories (for example, standing fit at upper chest, bust, and waist), calculating combined means, and comparing the values with the Duncan Waller multiple comparison test which is used to determine whether multiple means are significantly different. In the table, means designated by the same letter are not significantly different at the .05 level.

A discriminant analysis was conducted in an attempt to determine if there was any relationship between anthropometry and the qualitative fit and comfort assessments for the MS-1. The analysis was first done with subjects who wore all sizes, and then -- to ensure that the size worn did not interfere with the results -- with only those subjects who wore size Medium. The analysis indicated that for side interference (No. 20 on Table 3), differences among the ratings appear to be dependent on front and back waist lengths and chest circumference.

The first linear discriminant function appeared to explain 98 percent of the variability for the subjects who wore size Medium. The function (LS1) is shown below.

$$LS1 = (-.02437 \times \text{chest circ}) + (.07423 \times \text{waist front}) + (.04272 \times \text{waist back})$$

TABLE 3

FIT AND COVERAGE ASSESSMENT
1=Good 2=Fair 3=Poor

STANDING FIT

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
1. UPPER CHEST	1	20	27	16
	2	10	10	15
	3	7	0	6
	Mean rating	1.6	1.3	1.7
2. BUST	1	23	31	8
	2	11	6	24
	3	3	0	5
	Mean rating	1.5	1.2	1.9
3. WAIST	1	9	37	5
	2	21	0	22
	3	7	0	10
	Mean rating	1.9	1.0	1.9

STANDING COVERAGE

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
4. TOP	1	34	25	6
	2	3	11	26
	3	0	1	5
	Mean rating	1.1	1.4	2.0
5. FRONT ARMHOLES	1	14	14	7
	2	20	15	19
	3	3	8	11
	Mean rating	1.7	1.8	2.1
6. BOTTOM	1	36	36	29
	2	1	0	8
	3	0	1	0
	Mean rating	1.0	1.1	1.2
7. SIDES	1	36	37	21
	2	1	0	16
	3	0	0	0
	Mean rating	1.0	1.0	1.4

TABLE 3 (cont'd)

STANDING COVERAGE (cont'd)

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
8. BACK (TOP)	1	6	13	1
	2	28	20	16
	3	3	4	20
	Mean rating	1.9	1.8	2.5
9. BACK (ARMHOLES)	1	19	18	15
	2	17	18	17
	3	1	1	5
	Mean rating	1.5	1.5	1.7

SEATED FIT

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
10. UPPER CHEST	1	11	21	12
	2	15	11	13
	3	11	5	12
	Mean rating	2.0	1.6	2.0
11. BUST	1	20	30	6
	2	13	6	23
	3	4	1	8
	Mean rating	1.6	1.2	2.1
12. WAIST	1	15	36	7
	2	18	1	21
	3	4	0	9
	Mean rating	1.7	1.0	2.1

SEATED COVERAGE

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
13. TOP	1	34	32	7
	2	2	5	22
	3	1	0	8
	Mean rating	1.1	1.1	2.0

TABLE 3 (cont'd)

SEATED COVERAGE (cont'd)

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
14. FRONT (ARMHOLES)	1	25	22	9
	2	10	10	23
	3	2	5	5
	Mean rating	1.4	1.5	1.9
15. BOTTOM	1	37	37	36
	2	0	0	1
	3	0	0	0
	Mean rating	1.0	1.0	1.0
16. SIDES	1	37	37	22
	2	0	0	12
	3	0	0	3
	Mean rating	1.0	1.0	1.5

MOVEMENT COVERAGE

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
17. BACK COVERAGE BENDING FORWARD	1	22	24	23
	2	6	10	11
	3	9	3	3
	Mean rating	1.6	1.4	1.5
18. TOP COVERAGE BENDING FORWARD	1	26	28	7
	2	7	6	18
	3	4	3	12
	Mean rating	1.4	1.3	2.1
19. ARMHOLES BENDING AND TWISTING	1	34	27	31
	2	3	5	4
	3	0	5	2
	Mean rating	1.1	1.4	1.2

INTERFERENCE

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
20. VEST STRIKING OR DIGGING INTO SUBJECT'S SIDE DURING MOVEMENT	1	8	6	29
	2	12	16	8
	3	17	15	0
	Mean rating	2.2	2.2	1.2

TABLE 3 (cont'd)

INTERFERENCE (cont'd)

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
21. VEST SHIFTING DURING MOVEMENT	1	2	3	24
	2	19	22	12
	3	16	11	1
	Mean rating	2.4	2.2	1.4
22. RETAINED VEST SHIFT AFTER MOVEMENT	1	33	35	37
	2	3	0	0
	3	1	2	0
	Mean rating	1.1	1.1	1.0
23. VEST BINDING OR INTERFERENCE IN ASSUMING THE STANDING SHOOTING POSITION	1	1	16	11
	2	8	15	16
	3	28	6	10
	Mean rating	2.7	1.7	2.0
24. VEST INTERFERENCE OR BINDING WITH UTILITY BELT	1	18	11	36
	2	9	15	1
	3	10	11	0
	Mean rating	1.8	2.0	1.0
25. VEST SHIFTING OUT OF POSITION WHILE SEATED	1	21	15	31
	2	9	16	6
	3	7	6	0
	Mean rating	1.6	1.8	1.1
26. DIGGING INTO THE WAIST AT THE BOTTOM FRONT	1	20	23	35
	2	11	6	2
	3	6	8	0
	Mean rating	1.6	1.6	1.1

CHAFING

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
27. WHILE SEATED	1	24	13	34
	2	10	8	2
	3	3	16	1
	Mean rating	1.4	2.1	1.1
28. DURING MOVEMENT	1	17	19	31
	2	10	9	5
	3	10	9	1
	Mean rating	1.8	1.7	1.2

TABLE 3 (cont'd)

OVERALL RATING

	Rating	Frequencies Natick MS-1	Blue	T-Shirt
29. FIT/COVERAGE	1	18	19	5
	2	12	16	23
	3	7	2	9
	Mean rating	1.7	1.5	2.1
30. COMFORT	1	11	20	10
	2	13	8	12
	3	13	9	15
	Mean rating	2.1	1.7	2.1

TABLE 4

MEANS AND DUNCAN WALLER* RESULTS OF
FIT AND COVERAGE ASSESSMENT
1=Good 2=Fair 3=Poor

	Natick	Blue	T-Shirt
Standing Fit	1.68 B	1.14 A	1.93 C
Standing Coverage	1.38 A	1.42 A	1.83 B
Seated Fit	1.76 B	1.27 A	2.04 C
Seated Coverage	1.12 A	1.17 A	1.61 B
Movement Coverage	1.44 A	1.44 A	1.47 A
Interference	1.98 B	1.84 B	1.29 A
Chafing	1.62 B	1.91 C	1.15 A
Overall Rating	1.88 B	1.62 A	2.12 B

* Means with the same letter are not significantly different.

Figure 13 illustrates how this function differs as side interference changes. Subjects who were rated 1 for side interference (they had no difficulty) tended to have the largest LS1 scores, and those rated 3 (they had much difficulty) tended to have the lowest LS1 socres. Thus the larger the score on this function the less the interference problem. This can be interpreted to mean that when both waist front and waist back are long and at the same time chest circumference is small, the subjects experienced less interference. As the chest measure gets larger or the waist lengths get shorter, the fit degrades. This indicates that shorter vests appear to be needed if the interference at the side is to be alleviated. The results for the total group of subjects were essentially the same as those for the size Medium subjects.

DISCUSSION

Several areas of this evaluation required decisions based on trade-offs between fit, coverage, and comfort. The first such assessment involved the assignment of vest sizes to subjects. Small vests short enough to allow a subject to sit comfortably often left the armhole area exposed. The larger vest which usually provided better armhole coverage, was bulky and uncomfortable. Size assignment involved a compromise but was weighted toward coverage.

The second trade-off concerned snug versus loose-fitting armor. While a good fit was generally considered to be a snug fit, the loose armor (and particularly the T-shirt type vest) was more comfortable during movement. For that reason many subjects preferred the T-shirt vest to the others in their evaluations.

Trade-offs between coverage and movement are involved in determining optimum waist length, and in considering coverage at the armhole which is inversely related to interference in the shooting positions.

The indications from the summary of the qualitative assessments were that the Natick-designed MS-1 compared quite well to the other two vests. It was as good or better than the T-shirt vest in all categories except one (interference) and, while it did not fit as snugly as the blue vest, it did as well or better than the blue on all coverage and comfort evaluations.

Some of the fit problems of the MS-1 can be directly related to its velcro strap system. As can be seen in Figures 14 and 15, the straps are pulled beyond the receiving area of the velcro. Four subjects had a sufficient amount of velcro to adjust the vest properly, five received a fair evaluation, and 28 could not adjust the straps even reasonably well. A large area of velcro on the abdomen (see Figure 16), as well as a much larger area of velcro at the shoulders, could vastly improve the fit of the vest. In addition, the looseness of the elastic shoulder straps allowed the vest to hang so low on the torso that tightening the straps helped very little. A less elastic material should improve this problem, although care should be taken to ensure that straps are not so firm as to unduly restrict movement.

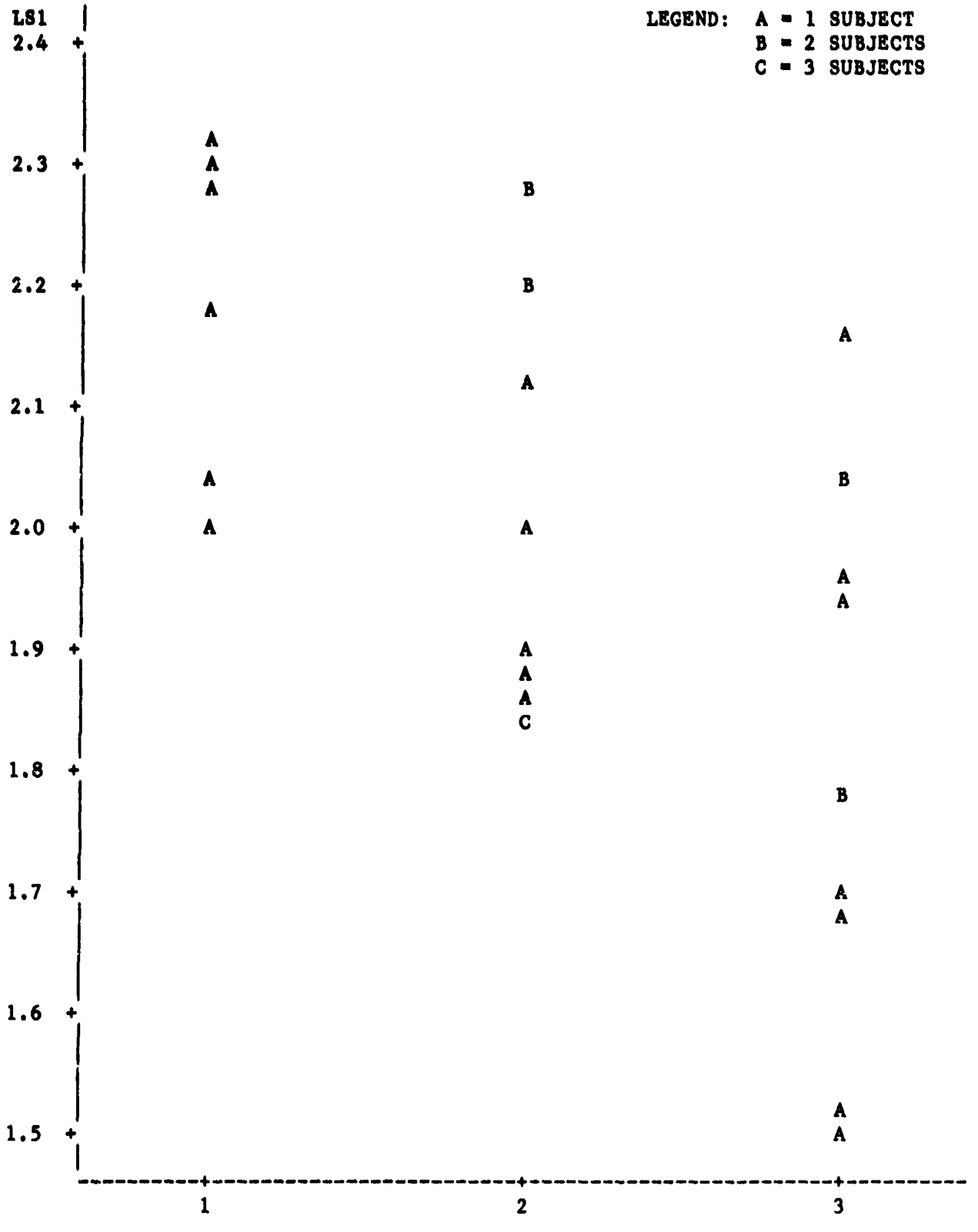


Figure 13. Plot of discriminant function scores for side interference ratings.

Figure 14. Lack of sufficient adjustability on the sides.

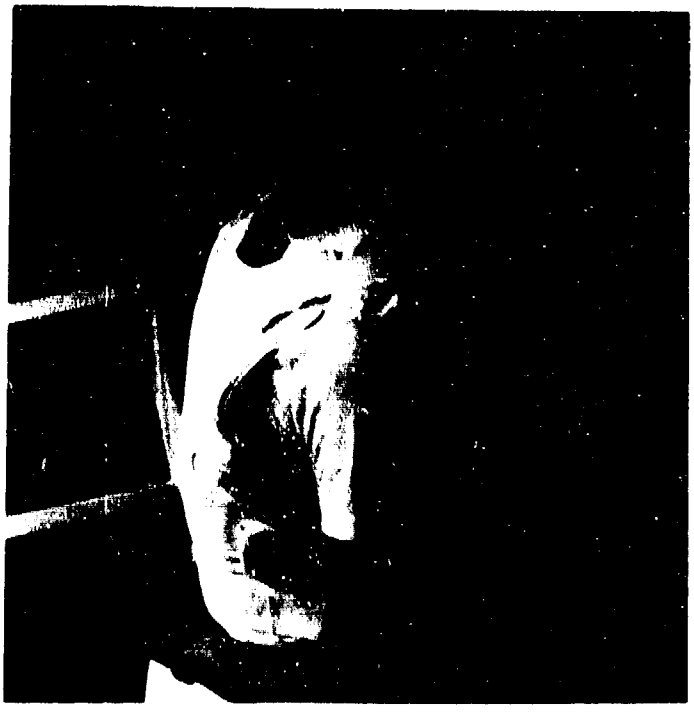


Figure 15. Lack of sufficient adjustability at the top.

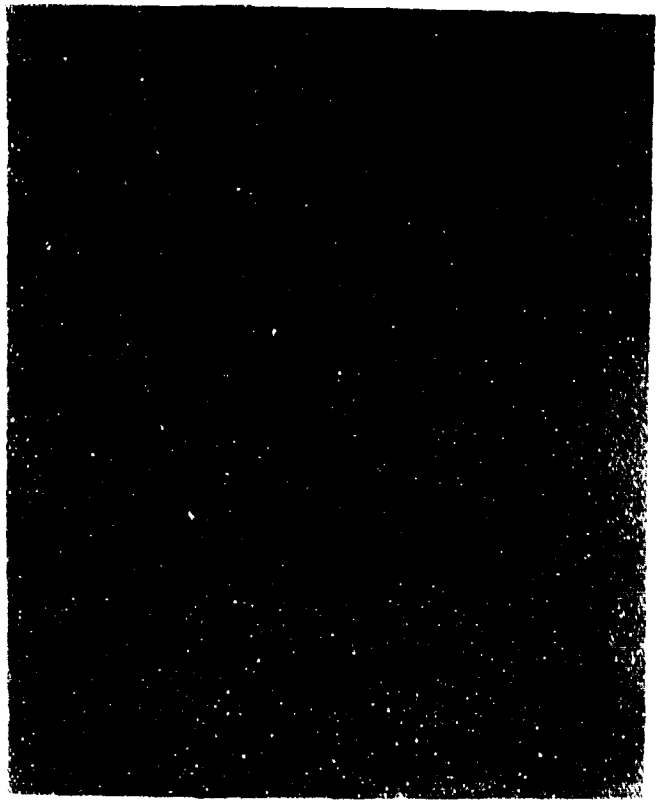


Figure 16. Examples of expanded velcro receiving area.

In addition to the need for an improved fastening system, shorter sizes are needed. It is possible that the original MS-1 sizing system included shorter sizes, although they are not now available as Air Force issue.

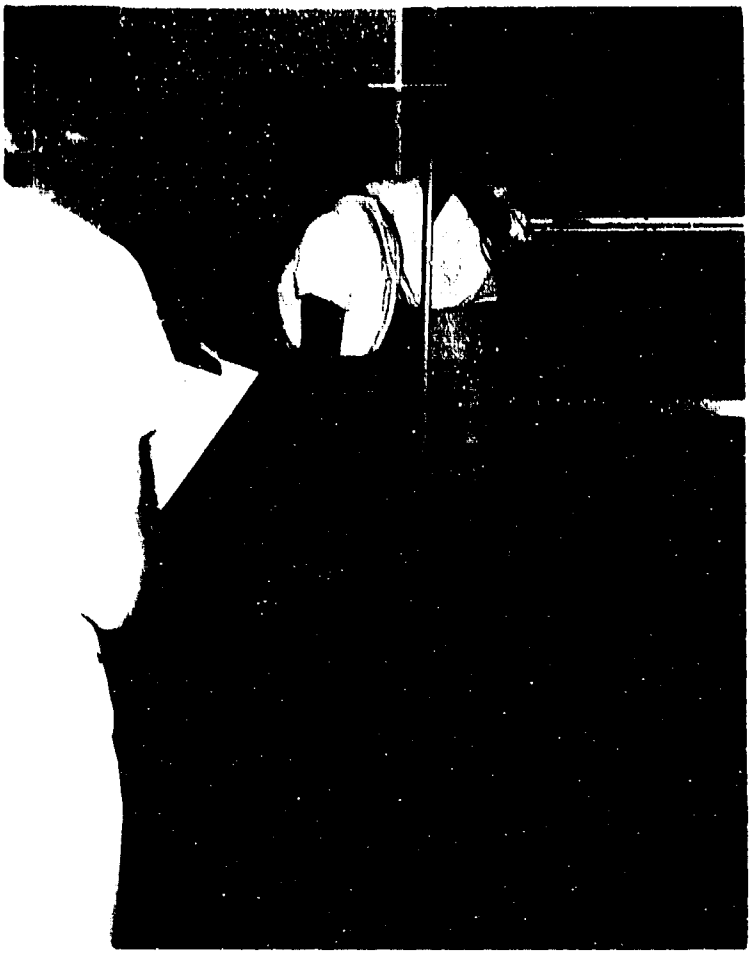
Since sizes Medium and Large of the currently issued MS-1 vests were sufficient to accommodate all the subjects in this study circumferentially, it is possible that the addition of two shorter sizes and improved velcro fastenings may markedly improve the overall fit and coverage of this vest. A four-size system (Medium Regular, Medium Short, Large Regular, and Large Short) may suffice to solve some of the problems without major redesign of the vest.

It should be stressed, however, that any such changes will interact with each other in ways which cannot be determined in advance. Loose straps, for example, seemed to increase the offset of the vest in the upper chest on some subjects and, at the expense of snugness, allowed more movement. Tightening the straps may solve one problem but cause another. Thus, no sizing or strap changes should be instituted without new fit tests of the modified vests.

APPENDIX

THE MEASUREMENTS

LIGHTLY CLAD MEASUREMENTS



HEIGHT

The vertical distance from the standing surface to the top of the head.

SUPRASTERNALE HEIGHT

The vertical distance between the standing surface and the deepest depression at the top of the breastbone (suprasternale).

WAIST HEIGHT

The vertical distance between the standing surface and the level of the subject's preferred waist.

CERVICALE HEIGHT

The vertical distance from the standing surface to the back of the base of the neck (cervicale).

CHEST CIRCUMFERENCE

The circumference of the chest at the level of the nipples.

INTERSCYE FRONT

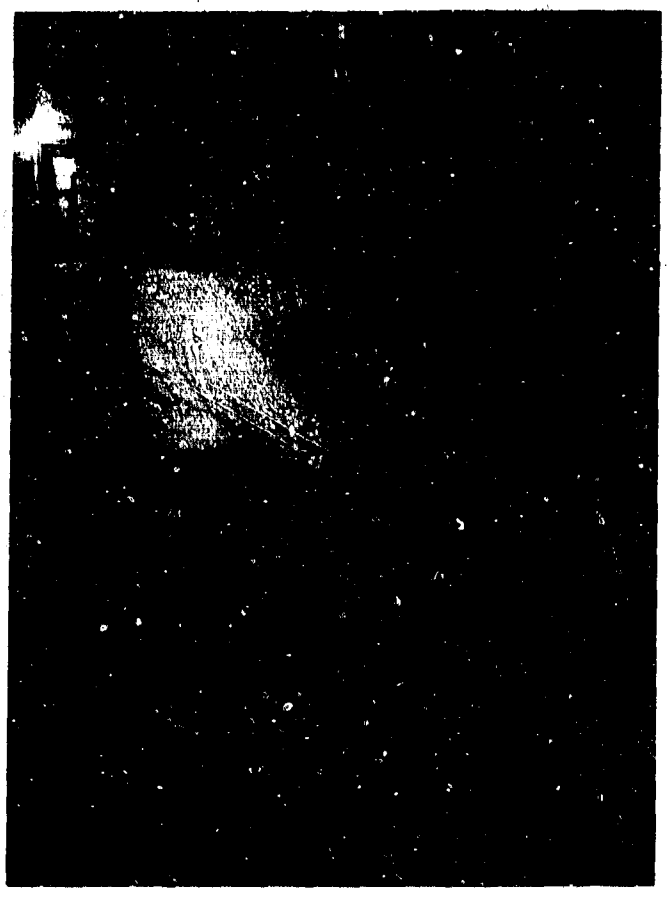
The horizontal surface distance across the front, between the lowest points on the anterior axillary folds.

WAIST FRONT

The surface distance between the suprasternale landmark and the level of the natural waist.

INTERSCYE BACK

The horizontal surface distance across the back, between the lowest points on the posterior axillary folds.

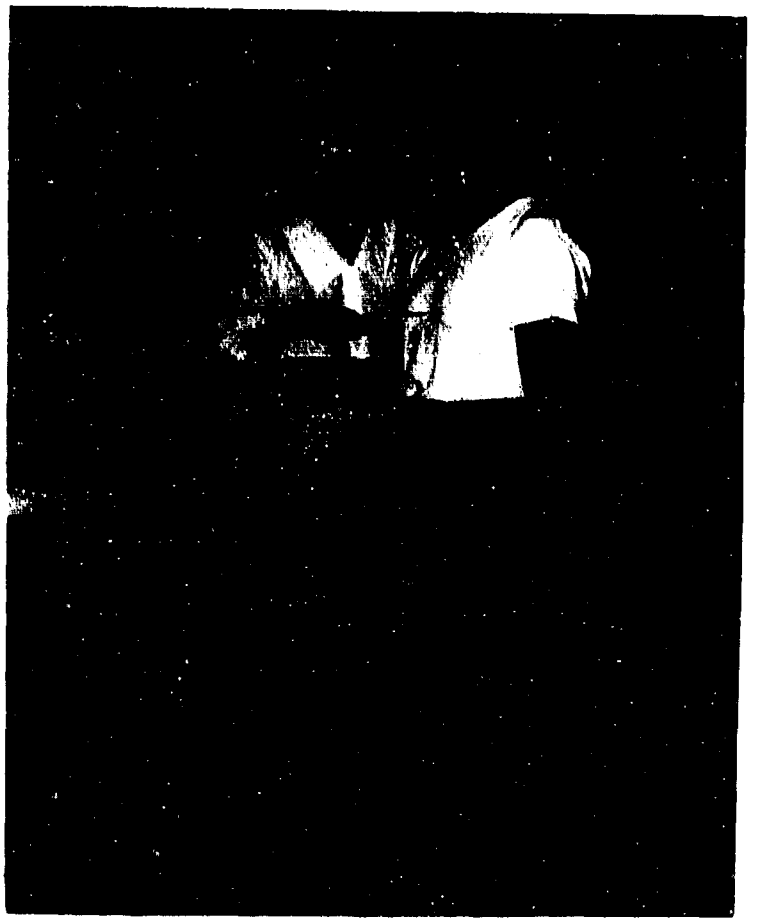


WAIST BACK

The surface distance between the cervicale and the level of the natural waist.

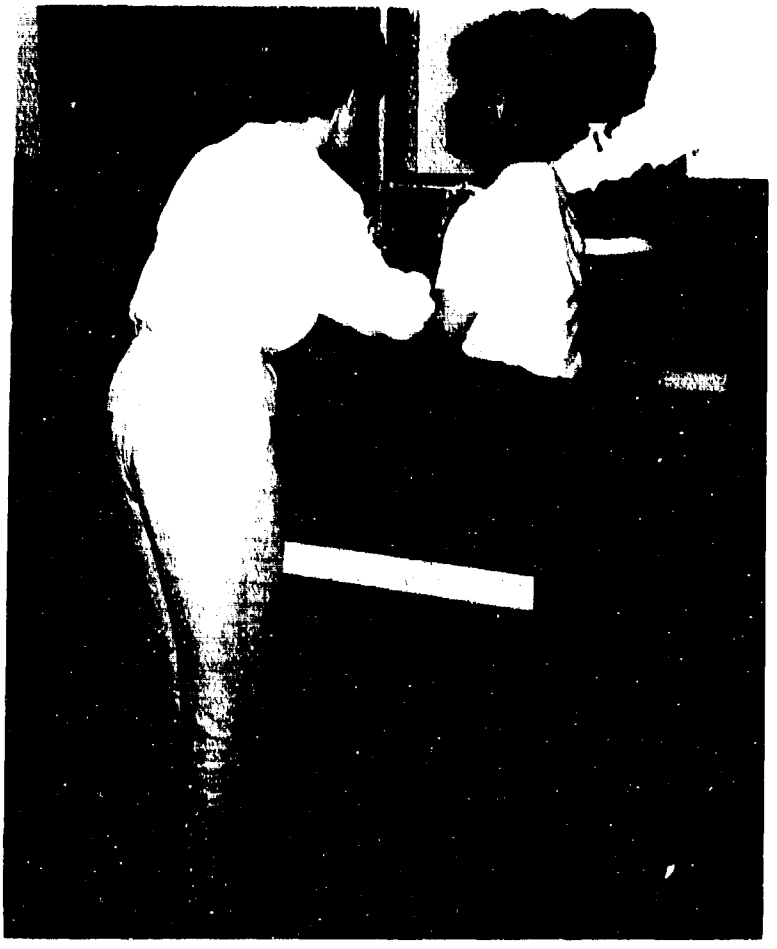
CHEST DEPTH, MIDSAGITTAL

The horizontal depth of the chest between the breasts at nipple level.



CHEST DEPTH, BUSTPOINT

The horizontal depth of the chest at the level of the nipples.



SUPRASTERNALE HEIGHT, SITTING

The vertical distance between the sitting surface and the point of the deepest depression at the top of the breastbone (suprasternale).

CHEST DEPTH, BUSTPOINT

The horizontal depth of the chest at the level of the nipples.

CHEST DEPTH, MIDSAGITTAL

The horizontal depth of the chest between the breasts at the level of the nipples.

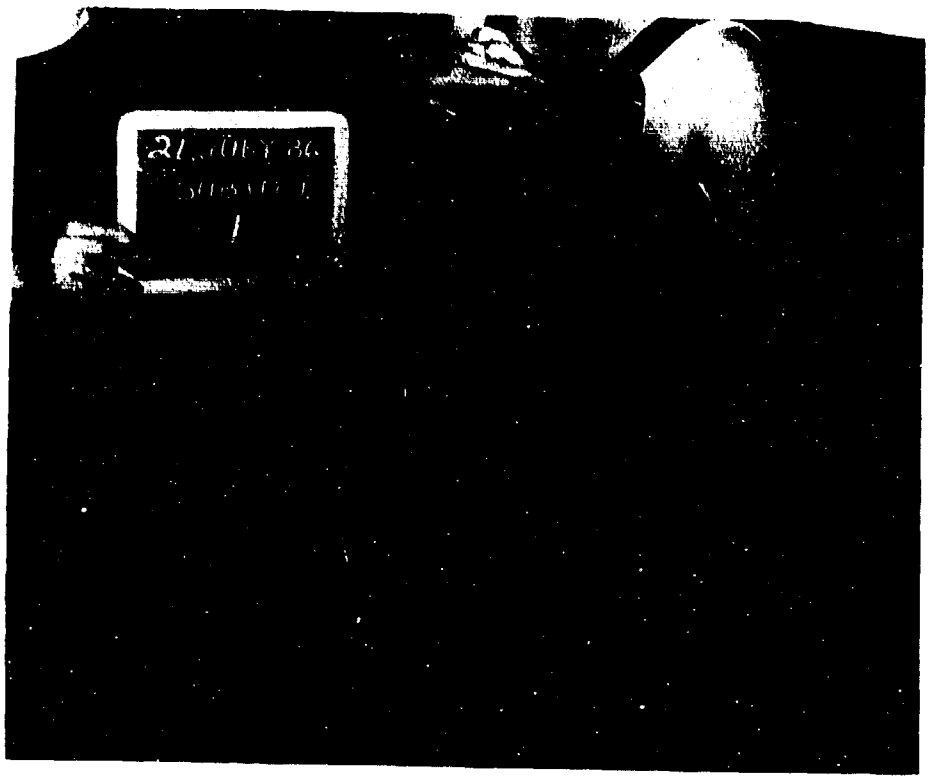
KEVLAR BOTTOM HEIGHT, FRONT

The vertical distance between the standing surface and the bottom of the front Kevlar panel.

KEVLAR TOP HEIGHT, BACK

The vertical distance between the standing surface and the top of the back Kevlar panel.

VESTED MEASUREMENTS*



KEVLAR TOP HEIGHT, FRONT

The vertical distance between the standing surface and the top of the front Kevlar panel.

---

* All vested measurements were taken with minimal pressure to the armor.

CERVICALE HEIGHT, SITTING

The vertical distance from the sitting surface to the back of the base of the neck (cervicale).

GAP DEPTH, FRONT

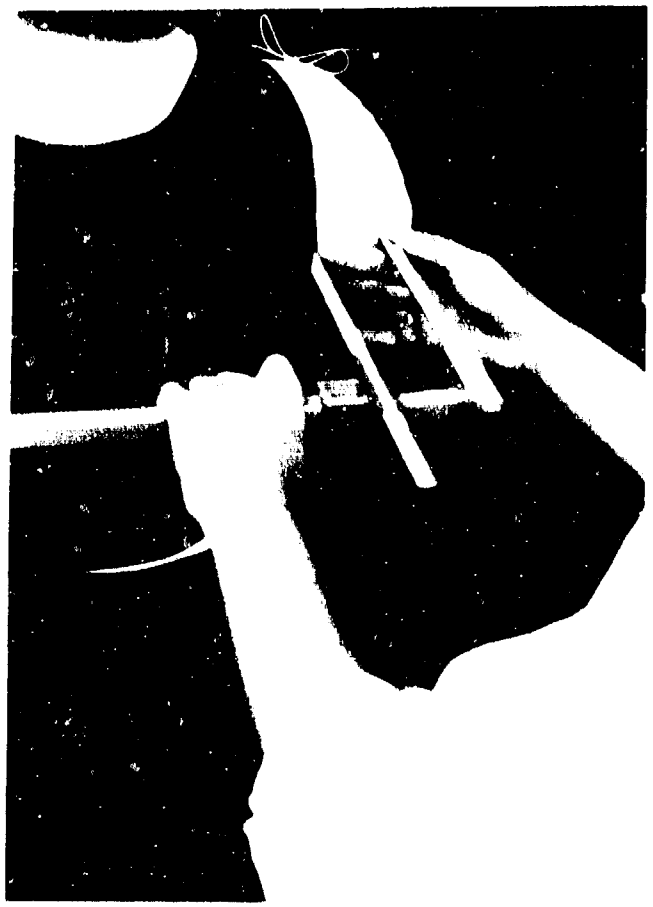
The horizontal exposed surface between the axilla and the Kevlar edge.

GAP BREADTH, FRONT

The horizontal surface distance in the front between the right anterior axillary fold and the Kevlar ledge.

GAP HEIGHT, UNDER ARM

The vertical surface distance between the axilla and the Kevlar edge.



GAP BREADTH, BACK

The horizontal surface distance in the back between the right anterior axillary fold and the Kevlar edge.

VESTED MEASUREMENTS (cont'd)

GAP AT SIDE

The horizontal surface distance between the Kevlar panels at the right side.

KEVLAR TOP HEIGHT, FRONT, SITTING

The vertical distance between the sitting surface and the top of the front Kevlar panels.

KEVLAR TOP HEIGHT, BACK, SITTING

The vertical distance between the sitting surface and the top of the back Kevlar panels.

★ U.S. GOVERNMENT PRINTING OFFICE 1988 - 548-002/60227